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THE SUCCESS/FAILURE OF METHODS USED TO PREDICT THE STRIPPING PROPENSITY IN THE PERFORMANCE OF BITUMINOUS PAVEMENT MIXTURES

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ABSTRACT

This effort presents a study of the apparent success/failure patterns of various test methods used to assess the stripping propensity of bituminous mixtures. The methods included are National Cooperative Highway Research Program (NCHRP) 246, NCHRP 274, Immersion-Compression, Boil Test, and the Nevada Dynamic Strip Method.

The analysis demonstrates that a possibility exists to develop a rating system for superiority of one test method over another. This rating was not possible in this work with the size of data base, non-commonality of the mixes used with the various test methods discussed, and use of published data without the full knowledge of the experimental variables.

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THE SUCCESS/FAILURE OF METHODS USED TO PREDICT THE STRIPPING PROPENSITY IN THE PERFORMANCE OF BITUMINOUS PAVEMENT MIXTURES

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I. INTRODUCTION

This effort discusses “successful” and/or “failure” examples from stripping prediction tests using laboratory and field records. Successful examples shall constitute a match between laboratory prediction and field performance. The converse shall be where laboratory predictions did not match field performance. Success or failure shall be assessed on the basis of a particular test method. The methods included in the discussion shall be two versions of the Indirect Tensile Test, that is National Cooperative Highway Research Program (NCHRP) 246, NCHRP 274; Immersion Compression, the 10-minute Boil Test, and the Nevada Dynamic Strip Test. The information presented in this report was compiled using the following criteria:

- Search for general and varied data sources;
- Minimize use of data listed by developers of the test methods which are discussed in this report in order to lessen the impact on the results of the success/failure ratings; and
- Full knowledge that field evaluations for example “moderate to severe” are not exact and/or reproducible.

Stripping prediction is a complex problem which has beseiged the asphalt technologist for decades. The complexity of the problem is manifested by the large population of tests used to evaluate the mixtures in both qualitative and quantitative terms. The availability of a diverse set of methods implies a general lack of understanding of the phenomenon on a fundamental and applied levels. Along with the large number of test methods, is the diversity in the criteria used to distinguish stripping from nons tripping mixtures. The factors contributory to the diversity of methods development include:

- Lack of fundamental understanding of the stripping mechanisms;
- Localized material properties;
- Climatic diversity;
- Non-universal asphalt-aggregate mixture behavior;
- Uncertainties in establishing threshold mixture strength values;
- As well as other factors.

The factors which contribute to the stochastic nature of predicting the stripping propensity without certainty include:

- Diversity of material types (aggregates, asphalts, additives);
- Mix design;
- Construction quality control;
- Climatic conditions during construction;
- Drainage conditions during the service life of the pavement mixture;
- Incomplete material evaluations;
- Over-simplification of the stripping phenomenon;
- Unquantifiable process effects on the material properties (refinery operations, types of crushers, handling conditions of aggregates in quaries); and
- Traffic loads variability.

Unless one of the above factors distinctly affects the pavement’s performance, otherwise the effort in this report is not intended to evaluate the effects of the above listed factors on the test parameters presented and discussed later.

II. TEST METHODS

NCHRP 246 or "Lottman" Test

This test is composed of two major elements. The first element is the incorporation of the aspects of tensile strength to bituminous mixtures from the early efforts of T.W. Kennedy (*l*) and coworkers. The second element is the development of moisture conditioning procedures for bituminous mixtures by R.P. Lottman (*2*,*3*) in order to assess the moisture damage potential. Thence, the method is generally referred to as the "Lottman" method.

The original Lottman test conditions call for testing Marshall specimens both dry and moisture conditioned at 55°F (12.8°C) and at a load rate of 0.065 in/min. The data is functionally expressed as the ratio of wet to dry tensile strength and represented as tensile strength ratio (TSR). The Lottman moisture conditioning procedure lists both vacuum application and a freezing cycle of 15 hrs.

There have been numerous modifications to the Lottman procedure (*4-8*) which generally involve:

- Removing the freezing cycle;
- Changing the testing temperature from 55°F (*4-8*) to 77°F (25°C), the latter being a most common test temperature;
- Changing the rate of test from 0.065 to 2.0 in/min. The latter rate of test is most attuned with testing rates and testing machines widely available in bituminous laboratories;
- Increasing the number of freeze-thaw cycles to enhance discrimination between mixtures which are prepared with anti-stripping additives (*9*,*10*)
- Changing the TSR criteria from 0.70 set by Lottman to reflect local material characteristics;
- Void content of mixture; and
- Level of saturation prior to the hot conditioning stage (*5*).

NCHRP 274 or "Tunniciff and Root" Method

The NCHRP 274 or "Tunniciff and Root" method (*5*) is a modification of the Lottman Procedure. The modifications include:

- Load rate (2 in/min);
- Test temperature (77°F (25°C);
- Presaturation of 55 to 80 percent;
- Preparation of mixtures to void content of 7±1 percent; and
- No freeze cycle.

This procedure has been standardized by AASHTO as T 283-85. Three specimens each set dry and moisture conditioned are tested for tensile strength and the results are expressed as tensile strength ratio (TSR) defined earlier.

Immersion Compression

Immersion compression (I/C) ASTM D 1075 or AASHTO T165 is the oldest standard method by which quantitative stripping predictions on compacted bituminous mixtures have been made (*11*). This procedure tests 4x4 inch specimens prepared by double plunger method (ASTM D1074).

The I/C specimens are divided into two groups forming dry and wet sets. The wet set is usually conditioned in 120°F (48.9°C) bath for four days. The two sets are tested at 77°F (25°C) for compressive strength. The results are expressed as retained compression strength ratio representing the quotient between wet and dry strength. A threshold value of the ratio for non-stripping mixtures is 75 percent.

The modifications to this procedure are generally as follows:

- Plunger pressure lowered to create large void spaces (*5*,*12*);
- Loading rate often varied (from a maximum of 2 in per minute to 0.2 in per minute (*13*));
- The ratio is varied depending on the pavement layer being evaluated, region using the test, traffic intensity; and
- Batch size varied to a minimum of four specimens (*13*) from the usual six specimens.

Boil Test (Ten-Minute Version)

This test is a modification of the standard ASTM D3625 test. The Boil test (ten-minute) is used widely by a number of State DOTs and research institutions as a quick test to determine the level of coating retained by an asphalt-aggregate combination. The mixtures are tested with or without additives. The test can be used on a . slice of the gradation or the complete gradation and also on field and laboratory mixtures. It is most criticized for the subjectivity of the test results and for using information from a slice to infer performance of a whole mixture.

The most diversely modified aspects of this test include:

- The retained coating criteria ranging from 60 to 100 percent. ASTM D3625 requires a minimum of 95 percent;
- The test environments, that is laboratory and or field;
- Decantation of water after the boiling process, that is, whether the water should be poured off right away or after it cools to ambient conditions (*14*);
- Whether the boiling mixture should be stirred or not (*14*);
- Variations of the heating temperature as some DOTs use the 140°F for this test (*15*); and
- Sample size.

Nevada Dynamic Strip Test

The Nevada Dynamic Strip Method (*16*) test was developed within the State of Nevada DOT and has been used more than 18 years to test Hveem specimens for predicting stripping propensity. Specimens 4 in diameter and 2.5 in thick are immersed in 140°F (60°C) bath for 144 hours (or six days). The conditioned specimens are rapidly cooled to 41°F (5°C) by packing with ice and then tumbled 1000 revolutions at 33 rpm to determine durability. Durability is indicated by the amount of weight loss due to the conditioning and tumbling process. The threshold criterion index is 25 percent weight loss (maximum).

This test is reported by Nevada DOT testing engineers as being very successful for the first 12 of its 18 years of existence. Doubt in the method’s capability has grown in the last six years because predictions have not consistently matched field performance and hence, alternate test methods are currently under consideration.

III. MATERIALS AND LOCATIONS

Materials

The following general classes of aggregates were used in the various studies:

1. Limestones
2. Dolomite
3. Granite
4. chert
5. Gravels
6. Sands
7. Combinations

The asphalts used were not identified for purposes of this report.

Locations

The data used in this report represent materials from the following states:

1. Alabama
2. California
3. Georgia
4. Kentucky
5. Louisiana
6. Mississippi
7. New York
8. Nevada
9. Tennessee
10. Texas
11. Utah
12. Virginia
l3. Washington

IV. COMPARATIVE RESULTS AND DISCUSSION

Results

Results consisting of laboratory predictions versus field performance are presented for each test method discussed above from published literature. The tabulations include an indication of whether the test was successful or a failure in the prediction. These rating terms were defined at the beginning of this report.

The assessment of success or failure of a prediction by a test method is based solely on two factors which are: a criterion ratio where it exists and the general field rating of the material. It is understood that none of these two factors are cast in stone. That is gray areas exist in the use of the ratio as well as the visual description of stripped mixtures. For example, the application of a TSR reproducibility criteria can affect the success/failure rating which will be demonstrated later.

Discussion

NCHRP 246 Test
The results in Table 1 show some measure of success and/or failure of this test in predicting moisture damage to a number of mixtures. It is important to note that a change in the TSR value, for instance, from 80 to 70 percent for the top five material systems, renders the Utah-Staker and

GA-Rome test predictions failures. Thus, the choice of the limiting criterion value can affect the assessment of the test capability.

The minimum criterion values listed correspond to those used in the reference publications and or specification in that jurisdiction. On the basis of TSR of 80 percent, and using this limited data set, this test would be successful 16 out of 21 cases or 76.1 percent. On the basis of 70 percent criterion, this test would be successful 14 out of 21 cases or 66.7 percent. The difference between these levels of success may not be significant because the reproducibility measured by coefficient of variation for this test has been indicated (25) to be more than 20 percent.

Table 1. Test Results on Mixtures Evaluated by Nchrp 246 Test

Test Method	Material Source	Strength or Crit. Ratio (%)		Field Performance Rating	Test Performance		Ref.
		Min. Req.	Test Result		Success	Failure	
NCHRP 246	GA - Grayson	80 (70)	6.5	Moderate to Severe	yes		(8)
	UT - Staker		77.2	Moderate to Severe	yes	(yes)	(8)
	GA - Rome	80 (70)	75.2	Slight	yes	(yes)	(8)
	MS - Hattiesburg (#l)	80 (70)	86.9	Slight		yes	(8)
	MS - Hattiesburg (#2)	80 (70)	84.8	Slight		yes	(8)
	GA - Grayson + A	80 (70)	92.9	Good	yes		(8)
	GA - Kennesaw + A	80 (70)	89.9	Good	yes		(8)
	GA - Rome + A	80 (70)	88.0	Good	yes		(8)
	MS - Hattiesburg #2+A	80 (70)	83.7	Good	yes		(8)
	TX - District 9	70	21	Stripper	yes		(17)
	TX - District 11	70	20	Stripper	yes		(17)
	TX - District 12	70	32	Stripper	yes		(17)
	TX - District 13	70	36	Stripper	yes		(17)
	TX - District 5	70	10	Non-Stripper		yes	(17)
	TX - District 12	70	18	Non-Stripper		yes	(17)
	TX - District 14	70	69	Non-Stripper		yes	(17)
	TX - District 19	70	80	Non-Stripper	yes		(17)
	VA - Aggregate	70 or 75	32	Stripper	yes		(9)
	WA - Aggregate	70 or 75	37	Stripper	yes		(9)
	TN - Aggregate	70 or 75	54	Stripper	yes		(9)
	KY - Aggregate	70 or 75	66	Stripper	yes		(9)

A = mixtures made with additive
Crit. = criteria
Min. = minimum
Req. = required
(yes) = represent effect of change of TSR criterion from 80 to 70 percent

NCHRP 274 Test

Table 2 lists data showing the relative success/failure pattern of predicitons by the NCHRP 274 test. On the basis of 70 to 80 percent criteria, this test is successful 10 out of 15 cases or 66.7 percent. This result does not mean that the latter method NCHRP 274, is inferior, equal, or superior to the predictive capability of the NCHRP 246 Method. The data set is small and, therefore, no inference can be made on the effect of criteria changes to the success/failure pattern of this test. However, a recent publication by Tunnicliff et al. (*26*) lists TSR reproducibility (D2S) by the NCHRP 274 test to be 23.0 percent. Applying this reproducibility limit to the 70 percent criterion implies that mixtures whose TSR indices range from 47 to 93 percent can be considered non-strippers. Application of this criterion and the precision limit to the data in Table 2 yields a 60 percent success and 40 percent failure in the predictions. This result is a downward shift from the 66.7 rating reported earlier.

Immersion-Compression Test

Table 3 lists data on the success/failure pattern of the I/C test. The data shows that the test is only successful seven out of 15 cases or 46.6 percent. This success rate nearly equals the reproducibility of the test stated as 50 percent in the precision statement in ASTM D 1075. However, the test method is widely used and is the oldest quantitative standard test.

Boil Test

The data in Table 4 lists a measure of success/failure pattern for the Boil Test method among the data obtained. From this data 57.9 percent of the cases are successful and only 42.1 percent failed. This test is highly subjective but very widely used according to recent surveys (*27*,*28*). However, the subjectivity of this test has been reduced by the recent development of a rating board by T.W. Kennedy and F.L. Roberts (*17*).

Nevada Dynamic Strip Test

Table 5 lists reported results using the Nevada Dynamic Strip Test which has had almost 67 percent success rate in the last 18 years. In the data shown, the test was succesfu1 only 36.4 percent of the time and failed 63.6 percent of the time, The reference time period for this listed data is within the last six years in which time the Nevada DOT has experienced an increasing trend of erroneous predictions by this test.

The results in Tables 1 through 5 can be presented graphically by plotting success versus failure as typified in Figure 1. This figure presents data from Table 1 (NCHRP 246 Method) showing success on the ordinate and failure on the abseissa. Success/failure ratings by this method and discussed earlier of 76.1/23.9 and 66.7/33.3 percent are shown in the figure. These ratings resulted from application of the 80 and 70 percent TSR criteria to the NCHRP 246 data in Table 1.

Table 2. Test Results on Mixtures Evaluated by Nchrp 2.74 Test

Test Method	Material Source	Strength or Crit. Ratio (%)		Field Performance Rating	Test Performance		Ref.
		Min. Req.	Test Result		Success	Failure	
NCHRP 274	GA - Grayson	70	10.5	Severe Stripper	yes		(18)
	GA - Rome	70	65.2	Slight Stripper	yes		(18)
	GA - Rome	80	76.8	Slight Stripper	yes		(8)
	MS - Hatiesburg #1	80	81.7	Slight Stripper		yes	(8)
	MS - Hattiesburg #2	80	75.9	Slight Stripper	yes		(8)
	GA - Grayson + A	80	92.7	Good	yes		(8)
	GA - Kennesaw + A	80	74.7	Good		yes	(8)
	GA - Norcross + A	80	89.4	Good	yes		(8)
	GA - Rome + A	80	83.8	Good	yes		(8)
	MS - Hattiesburg + A	80	90.9	Good	yes		(8)
	AL - Aggregate A	80	87	Non-Stripper	yes		(19)
	AL - Aggregate B	80	80	Severe Stripper		yes	(19)
	AL - Aggregate C	80	109	Moderate Stripper		yes	(19)
	AL - Aggregate D	80	107	Severe Stripper		yes	(19)
	AL - Aggregate E	80	85	Good or Non-Stripper	yes		(19)

A - Mixtures made with additives

Table 3. Test Results on Mixtures Evaluated Using Immersion Compression Test

Test Method	Material Source	Strength or Crit. Ratio (%)		Field Performance Rating	Test Performance		Ref.
		Min. Req.	Test Result		Success	Failure	
I/C	CA - Telchert	70	88.5	Very Good	yes		(20)
	CA - P.C.A. Fairoaks	70	56	Very Good		yes	(20)
	CA - Watsonville Granite	70	32	Very Good		yes	(20)
	NY - Crushed Granitic Gravel	75	80	Stripper		yes	(12, 21)
	NY - Crushed Limestone & Quartz Gravel Blend	75	71	Stripper	yes	yes	(12, 21)
	NY - Crushed Limestone & Gravel Blend	75	56	Stripper	yes		(12, 21)
	NY - Crushed Dolomite	75	41	Non-Stripper		yes	(12, 21)
	GA - Grayson	75	16.4	Moderate to Severe Stripper	yes		(8)
	UT - Staker	75	55.7	Moderate to Severe Stripper	yes		(8)
	GA - Rome	75	84.6	Slight Stripper		yes	(8)
	GA - Grayson + A	75	96.8	Good	yes		(8)
	GA - Rome + A	75	83.7	Goodpper	yes		(8)
	LA - A613 - Mix Z	75	87.4	Stripper		yes	(22)
	LA - A123 - Mix G	75	103.0	Stripper		yes	(22)
	LA - A070 - Mix H	75	107.8	Stripper		yes	(22)

A - Mixtures made with additives

Table 4. Test Results on Mixtures Evaluated by Ten-minute Boil Test

Test Method	Material Source		Retained Coating (%)		Field Performance Rating	Test Performance		Ref.
			Min. Req.	Test Result		Success	Failure	
Boil Test	AL[a]	A	90	70	Non-Stripper		yes	(<u>19</u>)
		B	90	55	Severe Stripper	yes		(<u>19</u>)
		C	90	95	Moderate Stripper		yes	(<u>19</u>)
		D	90	95	Severe Stripper		yes	(<u>19</u>)
		E	90	95	Non-Stripper	yes		(<u>19</u>)
	GA - Grayson		90	85	Mod. to Severe	yes	yes	(<u>19</u>)
	GA - Kennesaw		90	15	Mod. to Severe	yes		(<u>8</u>)
	UT - Staker		90	2.5	Mod. to Severe	yes		(<u>8</u>)
	GA - Rome		90	.5	Slight		yes	(<u>8</u>)
	MS - Hattiesburg #1		90	15	Slight		yes	(<u>8</u>)
	GA - Grayson + A		90	12.5	Good		yes	(<u>8</u>)
	GA - Rome + A		90	2.5	Good		yes	(<u>8</u>)
	Field Sand, 9E		85	55	Stripper	yes		(<u>17</u>)
	Coarse Field Sand, 13C		85	65	Stripper	yes		(<u>17</u>)
	Gem Sand, 13M		85	26	Stripper	yes		(<u>17</u>)
	Coarse Sand, 13N		85	65	Stripper	yes		(<u>17</u>)
	Sand Stone, 13L		85	85	Non-Stripper	yes		(<u>17</u>)
	Field Sand, 13D		85	85	Non-Stripper	yes		(<u>17</u>)

A = mixtures made with additive
a = surface mixes only without additives

Table 5. Test Results on Mixtures Evaluated by Nevada Dynamic Tumbling Test

Test Method	Material Source	Retained Coating (%)		Field Performance Rating	Test Performance		Ref.
		Min. Req.	Test Result		Success	Failure	
Dynamic Tumbling	I-80 near Deeth, Nevada	less than 25% weight loss	6.5-12.1%	Non-Stripping using Test Results		yes	(23)
	Elko, Nevada, Idaho Street	less than 25% weight loss	8.2-16.8%	Non-Stripping using Test Results		yes	(24)
	GA - Grayson	less than 25% weight loss	18.2	Moderate to Severe		yes	(8)
	GA - Kennesaw	less than 25% weight loss	3.0	Moderate to Severe		yes	(8)
	GA - Norcross	less than 25% weight loss	2.7	Moderate to Severe		yes	(8)
	GA - Rome	less than 25% weight loss	0.7	Slight		yes	(8)
	MS - Hattiesburg #1	less than 25% weight loss	5.6	Slight		yes	(8)
	GA - Grayson + A	less than 25% weight loss	1.5	Good	yes		(8)
	GA - Kennesaw + A	less than 25% weight loss	1.5	Good	yes		(8)
	GA - Norcross + A	less than 25% weight loss	1.5	Good	ye		(8)
	GA - Rome + A	less than 25% weight loss	0.4	Good	yes		(8)

A = mixtures made with additive

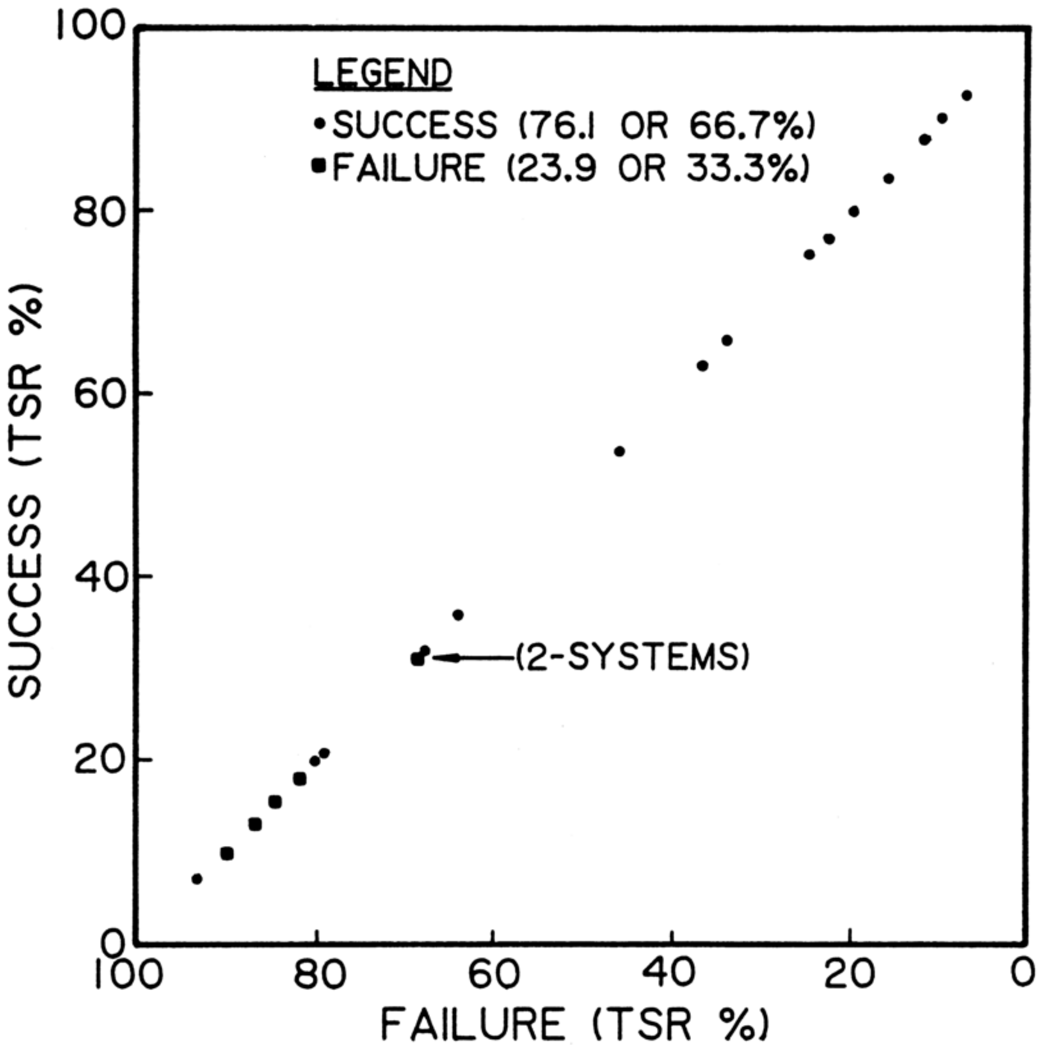

Figure 1. Success vs. Failure Predictions Using NCHRP 246 Test (Table 1)

V. CONCLUSIONS

From the limited data in this report, the following conclusions can be made:

- NCHRP 246 test listed a success rate of 76.1 percent;
- NCHRP 274 test listed a success rate of 66.7 percent;
- Immersion-Compression test showed a 46.6 percent success which compared favorably to its reproducibitility of 50 percent;
- The Boil test registered a 57.9 percent success;
- While the Nevada Dynamic Test registered a 36.4 percent success;
- The results do not indicate superiority of one test method over another because they were not all applied on a common set of materials;
- Success/Failure plots can be used to enhance data interpretation; and
- The success/failure pattern of a test method can be assessed though the evaluation is not totally deterministic because stripping is not caused by a single factor.

VI. RECOMMENDATIONS

1. There is a need to understand stripping mechanisms. The mechanisms are likely to be asphalt-aggregate specific, environmentally specific and service conditions specific. It is after understanding the mechanism(s) that appropriate test methods can be developed and/or rated.
2. There is a need to establish the success/failure rate of the available test methods by using properly designed experiment involving materials of known performance. These materials should be studied in the laboratory in the same condition they are used in the field. Such data will permit establishing a ranking system for stripping test methods which would allow determination of the superiority of given tests for specific conditions or environments.

VII. ACKNOWLEDGMENT

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